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EFFECT OF FRICTION STIR WELDING PARAMETERS ON IMPACT STRENGTH OF THE AZ31 MAGNESIUM ALLOY JOINTS

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ABSTRACT

In this experimental work, a study was done to see the effect of Friction stir welding parameters on the impact strength of the welded joints of AZ31 magnesium alloy. The AZ31 magnesium alloy was taken in form of plates with a thickness of 6mm. The plates were welded usinga tool made up of alloy steel using three different pin profiles i.e. cylindrical, tapered and threaded. The joints were welded at a three different rotational speeds keeping feed rate constant.The Impact strength of the welded joints was evaluated using Charpy test. Joints fabricated at the rotational speed of 1200 rpm with threaded pin profile showed better impact strength than the joint welded with other pin profiles. It shows as the as the rotational speed increases, a temperature of the weld increases which improves the ductility of the material which in turn improves the impact strength. More the contact surface of the pin profile more will be the impact strength. Results obtained mechanically is also verified by obtaining microstructures of base material i.e. AZ31 and nugget region obtained at 1200 rpm using threaded tool for FSW process.

KEYWORDS: Friction Stir Welding, Pin Profile, Rotational Speed & Impact Strength

Original Article

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INTRODUCTION

The Friction Stir Welding (FSW) is a solid- state joining process invented at The Welding Institute (TWI) in 1991(Thomas *et al*., 1991), Rhodes *et al.*, 1997). This process is widely used to weld aluminum magnesium, copper, titanium, steel & other alloys (Thomas *et al*., 1991), Mishra & Ma, 2005). Friction stir welding uses a tool which is rotating and non - consumable. The tool is of cylindrical shape with a pin of smaller diameter. The length of the pin is little smaller than the thickness of the plate and diameter of the pin is more than the thickness of the plate (Rajakumar & Balasubramanian, 2012). The rotating tool is plunged into the plate till it touches the top surface of the workpiece to be welded. The tool rotation and the feed rate of the tool helps in heat generation due to friction between the plate and the tool which results in the plastic deformation of the material and results in the stirring of the material at the interface of the joint which helps in the mixing of the material of the plates to be joined together (Forcellese *et al.*, 2012). Figure 1 explains the technique of FSW process. The friction of the tool against the workpiece provides heat which softens the material which is transferred from front of the tool to the back end which is further bonded together using the shoulder of the tool to make a joint. The shoulder of the tool provides the forging action.

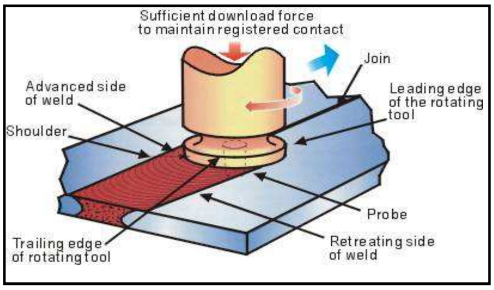


Figure 1: Schematic Representation of FSW Technique (Zhi-hong *et al.*, 2004)

Friction stir welding has many mechanical, metallurgical & environmental advantages as compared to conventional fusion welding techniques. There is an improvement in the mechanical properties of the welded joints. There are low distortion and good stability of the structure obtained after welding. The joints obtained using FSW is of high quality which is free from defects. There is a refinement of the grain structure during the process which enhances the strength of the joints. There is less consumption of fuel and energy during the FSW process. There is very less wastage of material and less emission of gases during the welding as compared to other welding processes. Due to the above -stated advantages,a lot of research work is going on to study the FSW process and its parameters.

FRICTION STIR WELDING PARAMETERS

Tool Material

Heat generation depends upon the material of the tool which can affect the quality of the weld produced. The tool material selected should have good shear strength, proper dimensional stability, wear resistance and oxidation resistance. H13 steel is widely used to weld magnesium alloys.

Tool Shape

FSW tool has a shoulder which is of concave shape which is used to escape the material and it maintains the downward pressure which helps in forging of the material. Pin part of the tool causes the stirring which helps in plastic deformation of the material and proper mixing. Pin shapes such as cylindrical, threaded, tapered, square etc can be used to weld magnesium alloys.

Tool Tilt

Tilting the tool at a certain angle helps in better bonding of joints. Tilting the welding tool by some angle has improved the welding of magnesium alloys.

Tool Rotation

Increasing the rotating speed of the tool results in more friction, which causes plastic deformation of the material. Increased heat input will generate more heat which will cause grain refinement. Increasing the tool rotating speed beyond a certain point can cause defects and coarsen of grain structure in some materials due to high temperature.

Feed Rate

Low feed rate helps in moving the tool easily along the material as low speed will help in generation of heat which will make the material plastic. High feed rate can result in voids and cracks in the weld due to insufficient heat.

Forces Acting on the Tool during Welding

Types of forces which are considered during the FSW process are the downward force which is important to maintain the tool position, traverse force which is parallel to the movement of the tool and the lateral force which is perpendicular to the tool traverse direction. These forces should be minimum as possible for proper welding.

FSW OF MAGNESIUM ALLOYS

Magnesium is a metal which is light in weight. Because of high specific mechanical properties, it is widely used in automobile, aerospace, optical, sports, electronics and other industries. Magnesium is a chemically active element which can easily form inter- metallic compounds with other alloying elements such as aluminum, titanium, zinc, copper etc. that is why it has been used in joining with other materials.

Therefore, detailed review of Friction stir welding of magnesium alloys has been done. Good quality of butt joints was obtained using FSW on 4 mm thick plates of AZ91Mg alloy plates at high welding speed and tool rotation (Lee *et al.*, 2003a). Defect -free welds of 4 mm thick AZ31B Mg alloy sheet were obtained at higher rotational speed and lower transverse speed (Lee *et al.*, 2003b). Size of weld nugget got increased during FSW of AZ31 magnesium alloy by increasing the ratio of rotational speed and transverse speed the (Gharacheh *et al.*, 2006). The FSW of 3.175 mm thick AZ31 Mg alloy plates showed better corrosion resistance than the base metal (Pareek, *et al.*, 2007). There was an improvement in the yield strength of the joint by increasing the welding speed (Afrin *et al.*, 2008, Zeng, *et al.*, 2008). There was an increase of ultimate tensile strength due to low heat input when friction stir welding of AZ31B magnesium alloy was done (Afrin *et al.*, 2008). The hardness of the FSW joints was increased (Afrin *et al.*, 2008, Zeng, *et al.*, 2008). The mechanical properties such as tensile strength etc. were reduced as compared to that of base metal AZ31B Mg alloy (Cao & Jahazi, 2009). It was found that by reducing the welding speed and simultaneously increasing the shoulder diameter & tool rotation speed will produce a high temperature which will improve the grain growth in AZ31 Mg alloy (Commin *et al.*, 2009). Friction stir welding lowers the yield strength and ultimate tensile strength but improves the strain hardening of AZ31B magnesium alloy (Chowdhury *et al.*, 2010). The FSW welding conditions formed the liquids and intermetallics during FSW of 6061 Al and AZ31 Mg alloy (Firouzdor & Kou, 2010). The microhardness of AZ31Bmagnesium alloy sheet added with 0.5 wt. % Ce was increased from top to bottom of the weld in FSW (Sirong *et al.*, 2010). Defect - free welds during FSW of 6 mm thick 5052 Al alloy and AZ31 Mg alloy plates were produced at tool rotation of 600 r/min and transverse speed of 40 mm/min (Yong *et al.*, 2010).

So keeping in view the above studies and experimentation, the present work is an attempt to understand the influences of rotational speed and pin profile of the tool on the impact strength of the friction stir welded joints of magnesium alloy.

EXPERIMENTAL WORK

The plates of magnesium alloy AZ31 of 6 mm thickness were cut as per the required dimensions. The composition of the AZ31 magnesium alloy is given in Table 1. Butt joints were prepared using a conventional milling machine. The plates were fixed on the bed of the machine using T-bolt clamps with a supporting bar of mild steel having a flat surface.

The rotational speed of 600, 900 and 1200 rpm with three different tool pin profiles i.e. Cylindrical (SC), Tapered

(TP) & Threaded (TH) were used to formulate the joints. The joints were prepared by passing the tool pin through the interface of the plates. The material used for welding tool is alloy steel of grade EN31. The specifications of the tools are given in Table 2. An initial depression of the shoulder was given to provide preheat and sufficient axial pressure.The various process parameters used for the experimentation are given in Table 3 and the process is shown in Figure 2. The number of welded specimens at different tool rotations & pin profiles is shown in Table 4.

Table 1: Work Piece Composition

Elements	(<,>,=)	Percentage
Magnesium	>=	95.14
Aluminum	<=	3.50
Zinc	<=	0.69
Manganese	<=	0.10

Table 2: Tool Material and Dimensions

Specifications	Values
Tool Material	EN31
Length of tool	60 mm
Tool shoulder diameter	20 mm
Pin diameter	6 mm
Pin length	5.8 mm
Taper angle	5°
Thread pitch	1mm

Table 3: Welding Process Parameters

Parameters	Values
Rotational Speed	600,900,1200rpm
Welding Speed	25 mm/min
Tool tilt	0°
Insertion of the shoulder on base material	0.1 mm

Table 4: Welded Specimens

Sr. No	Specimen No	Rotational Speed (RPM)	Tool Pin Profile
1.	J-1	600	Cylindrical(SC)
2.	J-2	900	Tapered(TP)
3.	J-3	1200	Threaded(TH)
4	J-4	600	Cylindrical(SC)
5.	J-5	900	Tapered(TP)
6.	J-6	1200	Threaded(TH)
7.	J-7	600	Cylindrical(SC)
8.	J-8	900	Tapered(TP)
9.	J-9	1200	Threaded(TH)

Figure 2: Welding Process

Impact Strength testing was done using Charpy test on Impact testing Machine. The standard Charpy V- notch specimen having dimensions 55mm x 10mm x10mm with 2mm deep notch having a tip radius of 0.25mm machined on one face as shown in figure 3 was prepared from the welded joints. The amount of energy absorbed in fracturing the test-piece was measured and this gives an indication of the notch toughness of the test material.

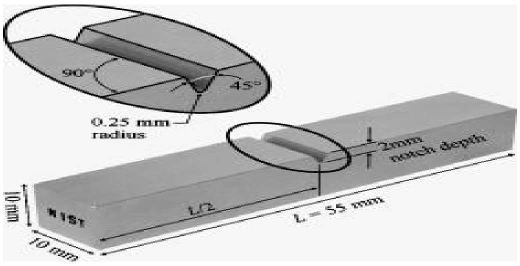
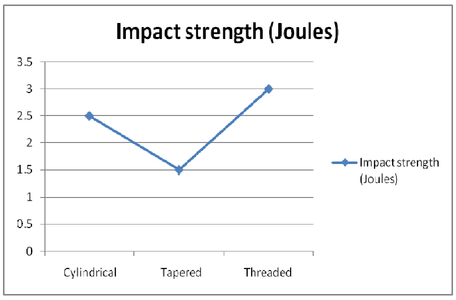


Figure 3: Dimensions of V-Notch Specimen

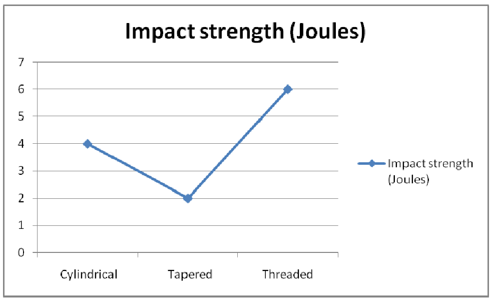
The results of impact strength of the base metal and welded specimens are shown in Table 5. The variation of Impact strength at particular tool rotation with different pin profiles is shown in Graphs 1-3 respectively.

Table 5: Impact Strength Results of Welded Specimens

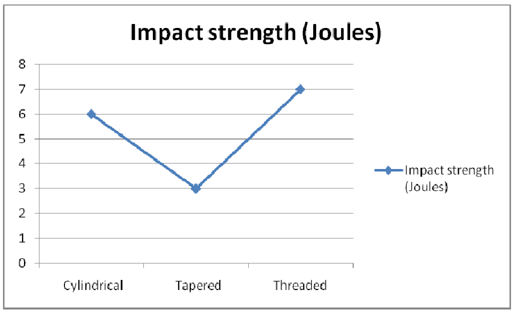
Sr. No	Specimen No	Rotational Speed (RPM)	Tool Pin Profile	Impact Strength(Joules)
1.	Base material	-	-	2
2.	J-1	600	Cylindrical(SC)	2.5
3.	J-2	600	Tapered(TP)	1.5
4	J-3	600	Threaded(TH)	03
5.	J-4	900	Cylindrical(SC)	04
6.	J-5	900	Tapered(TP)	02
7.	J-6	900	Threaded(TH)	06
8.	J-7	1200	Cylindrical(SC)	06
9.	J-8	1200	Tapered(TP)	03
10.	J-9	1200	Threaded(TH)	07



Graph 1: Variation of Impact Strength at 600 rpm



Graph 2 Variation of Impact Strength at 900 rpm



Graph 3: Variation of Impact Strength at 1200 rpm

DISCUSSION ON IMPACT TESTING RESULTS

Effect of tool rotation and pin shape on the impact strength of the FSW joints of AZ31 magnesium alloy was evaluated. From the graphs, it can find that the tool profile and tool rotational speed are having an influence on impact strength of the FSW joints. Threaded tool profile exhibited better impact strength as compared to other joints. The Impact strength of the base metal is 2 joules. The maximum impact strength is found to be 7 joules at 1200 rpm with threaded pin profile and the minimum impact strength is found to be 1.5 joules at 600 rpm with tapered pin profile.

DISCUSSION ON MICROSTRUCTURE

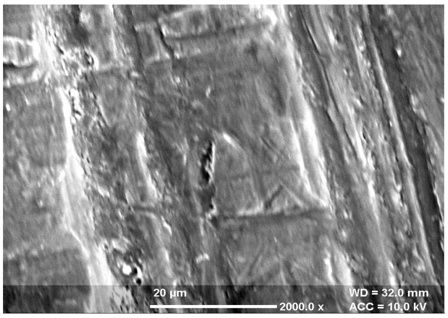


Figure 4: Microstructure of AZ31 Base Material

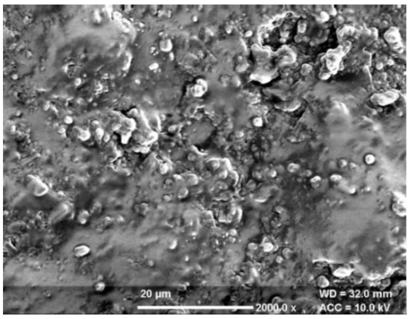


Figure 5: Microstructure of Nugget Region at 1200 rpm using Threaded Tool

The microstructure of base material i.e. AZ31 magnesium alloy showed the solid solution of Mg having a granular phase with deformation twins as shown in Figure 4. The microstructure in Figure 5 shows that impact strength of the joint made with 1200 rpm and using threaded tool was higher because of finer grains in the nugget region which are formed due to the proper stirring of the material and generation of heat due to high rotation of the tool. The Threaded tool has a larger interfacial area which increases the heat input which further improves the material flow and decreases the axial and transverse forces. Also, this shape helps inhomogenous distribution of particles in the weld zone which can be seen in the microstructure.

CONCLUSIONS

In this study, there is an effort to study the effect of tool rotation speed and pin profile on the impact strength of the welded joints of AZ31 magnesium alloy. From this study following results can be derived:

- Friction stir welding of AZ31 magnesium alloy can be done using the conventional vertical milling machine.
- Threaded pin profile gives a better quality of FSW joints having high impact strength as compared to other pin

profiles. This is due to threaded pin gives better stirring which leads to the proper plastic deformation of material and contact surface of the pin is more which bonds the joint well. More the contact surface area of pin more will be the strength of the weld.

- There is an increase in impact strength with increase in tool rotation speed. More the tool speed more will be the heat generation and refinement of the grains which will improve the ductility of the material and this will improve the impact strength of the FSW joints.

REFERENCES

1. *Afrin, N., Chen, D. L., Cao, X., & Jahazi, M. (2008). Microstructure and tensile properties of friction stir welded AZ31B magnesium alloy. Materials Science and Engineering: A, 472(1), 179-186. http://dx.doi.org/10.1016/ j.msea.2007.03.018*
2. *Cao, X., & Jahazi, M. (2009). Effect of welding speed on the quality of friction stir welded butt joints of a magnesium alloy. Materials & Design, 30(6), 2033-2042. http://dx.doi.org/10.1016/j.matdes.2008.08.040*
3. *Chowdhury, S. M., Chen, D. L., Bhole, S. D., & Cao, X. (2010). Tensile properties of a friction stir welded magnesium alloy: Effect of pin tool thread orientation and weld pitch. Materials Science and Engineering: A, 527(21), 6064-6075. http://dx.doi.org/10.1016/j.msea.2010.06.012*
4. *A. K. Darwins & M. Satheesh, Effect of Friction Stir Welding Processon Mechanical Properties and Microstructure of ZE42 Magnesium Alloy, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Volume 7, Issue 6, November - December 2017, pp. 429-436*
5. *A. K. Darwins & M. Satheesh, Effect of Friction Stir Welding Processon Mechanical Properties and Microstructure of ZE42 Magnesium Alloy, International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), Volume 7, Issue 6, November - December 2017, pp. 429-436*
6. *Commin, L., Dumont, M., Masse, J. E., & Barrallier, L. (2009). Friction stir welding of AZ31 magnesium alloy rolled sheets: Influence of processing parameters. Acta materialia, 57(2), 326-334. http://dx.doi.org/10.1016/j.actamat.2008.09.011*
7. *Firouzdor, V., & Kou, S. (2010). Al-to-Mg friction stir welding: effect of material position, travel speed, and rotation speed. Metallurgical and Materials Transactions A, 41(11), 2914-2935.DOI: 10.1007/s11661-010-0340-1*
8. *Forcellese, A., Gabrielli, F., & Simoncini, M. (2012). Mechanical properties and microstructure of joints in AZ31 thin sheets obtained by friction stir welding using “pin” and “pinless” tool configurations. Materials & Design, 34, 219-229. http://dx.doi.org/10.1016/j.matdes.2011.08.001*
9. *Gharacheh, M. A., Kokabi, A. H., Daneshi, G. H., Shalchi, B., & Sarrafi, R. (2006). The influence of the ratio of “rotational speed/traverse speed”(ω/v) on mechanical properties of AZ31 friction stir welds. International Journal of Machine Tools and Manufacture, 46(15), 1983-1987. http://dx.doi.org/10.1016/j.ijmachtools.2006.01.007*
10. *Lee, W. B., Kim, J. W., Yeon, Y. M., & Jung, S. B. (2003, a). The joint characteristics of friction stir welded AZ91D magnesium alloy. Materials Transactions, 44(5), 917-923.*
11. *Lee, W. B., Yeon, Y. M., & Jung, S. B. (2003, b). Joint properties of friction stir welded AZ31B–H24 magnesium alloy. Materials Science and Technology, 19(6), 785-790. http://dx.doi.org/10.1179/026708303225001867*
12. *Mishra, R. S., & Ma, Z. Y. (2005). Friction stir welding and processing. Materials Science and Engineering: R: Reports, 50(1-2), 1-78.*

13. *Pareek, M., Polar, A., Rumiche, F., & Indacochea, J. E. (2007). Metallurgical evaluation of AZ31B-H24 magnesium alloy friction stir welds. Journal of materials engineering and performance, 16(5), 655-662. DOI: 10.1007/s11665-007-9084-5*
14. *Rajakumar, S., & Balasubramanian, V. (2012). Correlation between weld nugget grain size, weld nugget hardness and tensile strength of friction stir welded commercial grade aluminium alloy joints. Materials & Design, 34, 242-251. http://dx.doi.org/10.1016 /j.matdes.2011.07.054*
15. *Rhodes, C. G., Mahoney, M. W., Bingel, W. H., Spurling, R. A., & Bampton, C. C. (1997). Effects of friction stir welding on microstructure of 7075 aluminum. Scripta materialia, 36(1), 69-75.*
16. *Sirong, Y., Xianjun, C., HUANG, Z., & Yaohui, L. I. U. (2010). Microstructure and mechanical properties of friction stir welding of AZ31B magnesium alloy added with cerium. Journal of rare earths, 28(2), 316-320. https://doi.org/10.1016/S1002-0721(09)60104-6*
17. *Thomas, W. M., Nicholas, E. D., Needham, J. C., Murch, M. G., Templesmith, P., & Dawes, C. J. (1991). GB Patent application no. 9125978.8. International Patent Application No. PCT/GB92/02203.*
18. *Yong, Y. A. N., Zhang, D. T., Cheng, Q. I. U., & Zhang, W. (2010). Dissimilar friction stir welding between 5052 aluminum alloy and AZ31 magnesium alloy. Transactions of Nonferrous Metals Society of China, 20, s619-s623. https://doi.org/10.1016/S1003-6326(10)60550-X*
19. *Zeng, R. C., Dietzel, W., Zettler, R., Jun, C. H. E. N., & Kainer, K. U. (2008). Microstructure evolution and tensile properties of friction-stir-welded AM50 magnesium alloy. Transactions of Nonferrous Metals Society of China, 18, s76-s80.*
20. *Zhi-hong, F. U., Di-qiu, H., & Hong, W. (2004). Friction stir welding of aluminum alloys. Journal of Wuhan University of Technology-Mater. Sci. Ed., 19(1), 61-64.*